Effects of Pre-Planting Soaking on Growth and Survival of Black Willow Cuttings

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Abstract

Black willow (*Salix nigra*) uses periodic flood events for dispersal of vegetative propagules, subjecting them to periods of soaking before their deposition along the streambank. It was hypothesized that this life history trait results in optimal conditions for willow growth and survival. To test this hypothesis, a greenhouse experiment was conducted using 1.2-m-long black willow cuttings (posts) with a basal diameter of 5 cm. Cuttings were subjected to three soaking treatments (0, 3, and 10 days) and then grown under four soil moisture regimes (control, drought, permanently flooded, and intermittently flooded). Growth, biomass, and survival were recorded. Results showed that soaking posts for 10 days was most beneficial in the control soil moisture regime, enhancing root, shoot, leaf, and total biomass production. Shoot abundance and growth were also enhanced by 10 days of soaking in the control and permanently flooded moisture regimes. Finally, survival increased significantly in control and drought moisture regimes in response to the 10-day soaking treatment. Results clearly demonstrated that soaking had significant effects on willow post success when evaluated across all soil moisture regimes. Posts subjected to the 10-day soaking treatment consistently had greatest growth and biomass and displayed a doubling of the survival rate. Therefore, soaking willow cuttings before planting is a simple, inexpensive technique that may be used to bolster streambank restoration success.

Key words: plant stress, riparian restoration, *Salix nigra*, soil moisture, streambank stabilization.

Introduction

Willow (*Salix* spp.) cuttings are commonly used as a cost-effective and efficient bioengineering tool to provide soil stabilization, erosion control, and habitat rehabilitation along highly erodible streambanks. For streambanks planted at 0.9-m centers and at least halfway up the bank from waters edge, Shields et al. (1995) suggested a willow post survival rate of about 50% after 2 years to provide good cover of streambanks, whereas Watson et al. (1995) suggested that 29% to 34% survival is needed for bank stabilization. However, many projects have had survival rates much lower, less than 10% in some cases (Wolfe 1992). Field and greenhouse studies have identified low soil redox potential (E_H), drought, and soil texture as important parameters that govern willow post survival and growth (Pezeshki et al. 1998). However, planting methods and pre-planting treatments may also play a critical role in improving the success of willow posts.

Black willow (*Salix nigra* Marshall.) is commonly found within floodplains of the bottomland hardwood forests of the southeastern United States (Mitsch & Gosselink 1993) and is classified as a flood-tolerant species (Hook 1984). *Salix* species commonly found within floodplains have been shown to produce more adventitious roots than species typically found in upland habitats (Krasny et al. 1988). This ability to rapidly produce adventitious roots is thought to be a key for the success of a willow post plantation. For example, Pallardy and Kozlowski (1979), using fast growing clones of rooted leafy species, showed that greater root weight per leaf area and increased rates of root elongation resulted in greater carbon assimilation rates and thus greater long-term biomass production. These researchers suggested that the establishment of a substantial root mass resulted in the ability of cuttings to avoid drought stress. Similarly, with a sufficient amount of water in the propagation medium, leaf turgor was restored through water absorption by the stem of unrooted cuttings (Grange & Loach 1983). Rein et al. (1991) showed that mid-day xylem pressure potential increased in stem cuttings of several ornamental species with increased water content in the propagation medium, indicating a favorable plant water status that enhanced adventitious root production and subsequent survival. Therefore, a pre-planting treatment that would increase the water content of willow cuttings may promote root initiation and devel-

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opment and provide long-term growth and survival benefits.

Previous work on certain woody species strongly suggests that pre-planting treatments such as soaking in water may significantly enhance their success (Petersen & Phipps 1976; Phipps et al. 1983). Soaking of cuttings significantly enhanced shoot and root growth in *Populus* spp., and the effects were noted 10 and 18 days after planting (Bloomberg 1963; Phipps et al. 1983). The results were attributed to the improved water content of the cuttings and to root and shoot initiation during the soaking period. However, it is not known if soaking would have the same beneficial effects on willow cuttings. *Salix* readily reproduces vegetatively using periodic flood events for dispersal of its woody propagules. Based on this life history trait, it is reasonable to hypothesize that soaking willow cuttings would enhance their growth and survival. A greenhouse study was designed to examine the effects of soaking on survival and growth of willow posts. The primary objective of this study was to quantify the overall effects of soaking across various soil moisture regimes. The specific objectives were (1) to evaluate the effects of pre-planting soaking treatment on willow post growth, biomass production, and survival within a range of soil moisture regimes typically observed in streambank restoration projects within northern Mississippi and (2) to characterize the relationship between soaking duration and growth and survival of willow posts.

Materials and Methods

Black willow posts were collected from a localized population along the floodplain of the Loosahatchie River in western Tennessee, U.S.A. Willow posts were collected according to bioengineering specifications (USDA Natural Resources Conservations Service 1996) to obtain posts of the quality typically encountered at a project site. Cuttings with a basal diameter of 5 cm and a total length of 1.2 m were harvested in late February and early March 1999 while plants were dormant. All secondary branches were removed from each post in compliance with standard planting practices (USDA Natural Resources Conservations Service 1996). Posts were either pre-soaked 10 days before planting, 3 days before planting, or were not soaked (control posts). All posts were harvested and bundled into groups. The lower 72 cm of each group were wrapped in WeedBlock (Easy Gardener, Waco, TX, U.S.A.), a black material designed to allow water and air flow to the posts but prevent light penetration. The wrap was used to promote initiation of rooting structures in the portion of the post that would subsequently be placed below ground. Each bundle was then placed in a nearby tributary to the river with a mean temperature of 10.15°C and a mean dissolved oxygen concentration of 8.96 mg/L and weighted to the bottom with rock to ensure similar levels of soaking. The day control posts were harvested, all cuttings were transported to the laboratory and stored in a cool dark room overnight and subsequently planted in the greenhouse the following day.

Containers 1.21 m long and 10.2 cm in diameter were constructed of polyvinyl chloride pipe and filled with two parts washed, medium-grained sand mixed with one part field soil (v/v). The field soil was collected from the A_p horizon (horizon disturbed by plowing) of a Sharkey Clay soil from an old agricultural field in Dyer County Tennessee. Sharkey Clay is typically a dark gray, poorly drained but fertile soil neutral in reaction (USDA Soil Conservation Service 1970). Caps were glued to the bottom of each container, and holes were drilled along the base to allow control of the soil moisture regime. A single post was planted in each container such that 72 cm of the post was below ground and 48 cm was above ground. The study was conducted in an air-conditioned greenhouse and used natural light that provided a daily maximum photosynthetic active radiation around 1,700 to 1,800 μmol/m^2 sec at the top of plant canopy during sunny days. Posts were maintained under well-watered and well-drained conditions (i.e., field capacity) for 12 days before initiation of soil moisture treatments. Posts were fertilized weekly with 200 mL of 20-20-20 Peters Fertilizer mixed with tap water at 1.25 g/L.

Four watering regimes were used to test the responses of soaked and unsoaked willow. The treatments represented a relatively wide range of soil moisture (and thus soil E_H) that could be expected in the field during a growing season. These treatments were as follows: (1) control, well watered but not flooded; (2) continuous flooding, water was kept at 5 cm above the soil surface throughout the experiment; (3) intermittent flooding, containers were flooded to 5 cm above the soil surface for 3 days and drained to 60 cm below soil surface for 10 days; and (4) drought, water was supplied to the containers on every fourth day. Watering events for all treatments consisted of the addition of approximately 1,000 mL of tap water twice a day. Drainage was collected in trays placed below each container and reapplied as a portion of this water volume. To monitor soil drought conditions periodic photosynthesis and stomatal conductance measurements were conducted and drought treatments were compared with control to confirm that drought conditions were present (data not shown). To monitor soil saturation, soil E_H was measured in all treatments at 15, 30, and 60 cm below the soil surface using platinum-tipped electrodes, a millivoltmeter, and a calomel reference electrode as described in detail elsewhere (Patrick & DeLaune 1977). The duration and frequency of flooding for the intermittent flooding treatment was determined from stage data collected at 15-minute intervals by the U.S. Geological Survey for the Twentymile Creek restoration site in Lee County, Mississippi. This site is a typical channelized stream with a long history of erosion. Thus, Twentymile Creek is representative of streams targeted for stabilization using this technique (Pezeshki et al. 2002), and its flood duration and frequency are characteristic of conditions typically observed in northern Mississippi. Analysis of the stage data for October 1989 through September 1993 indicated mean flood duration of approximately 80 hr at low elevation (12 cm) above base stream flow. Mean interflood period was determined to be 269 hr at 30 cm above base flow. Therefore, a slight modification of this mean (240 hr) was used for flood frequency, that is, intermittent containers were flooded for 3 days and drained for 10 days. These cycles were repeated approximately nine times.

The experiment followed a completely randomized design. Each soaking treatment consisted of 28 replicated cuttings for a total of 84 pots, each containing one post. All posts were planted on 2 March 1999. Soil moisture treatments were initiated 12 days later (14 March 1999). Harvesting was completed on 15 July 1999, and thus the experiment was concluded 136 days after initial planting.

Growth Measurements

Before planting, posts were evaluated for the presence or absence of root emergence, swollen root primordia, or bud formation. Sixteen days after planting, all posts were surveyed for presence or absence of buds. The number of buds for each post was recorded, and the percent bud flushing was calculated.

At the conclusion of the study, the posts were removed from the pots and soil was carefully washed from the roots. Each post was separated into live and dead components for roots, branches, and leaves. Growth variables measured include the number of live and dead primary and secondary shoots and the number of live and dead roots. A primary shoot was defined as any shoot originating at the post, whereas a secondary shoot was defined as any shoot originating from a primary shoot. The length of each primary shoot was recorded and summed, giving a total length for the growth of each post. All biomass components were placed in separate paper bags and oven dried at 70°C until reaching a constant weight. Root-shoot ratios for each soaking treatment were calculated using the total amount of live biomass for the aboveground and belowground components of each post. Finally, post survival was determined by the presence of any live biomass components such as live root, shoot, or leaf biomass.

Data Analysis

Differences between soaking treatments within each soil moisture regime were evaluated using the general linear models multivariate analysis of variance procedures of the Statistical Analysis System (Scheiner 1993). Pooled results for each soaking treatment were blocked on the soil moisture regime and the general linear models procedures were then used to determine the overall effects of the soaking pre-treatment across soil moisture regimes. Duncan's multiple range tests were used to indicate differences among individual treatment means at the $\alpha = 0.05$ level (SAS 1990).

Results

Before planting, no roots or swollen root primordia were visibly present on the cuttings. Sixteen days after the posts were planted, each cutting was inspected for the presence of buds as a means of determining initial post health. The number of buds per post was not significantly different across soaking treatments or soil moisture regimes. There was no clear relationship between pre-planting soaking and initial bud production or the percentage of posts that flushed buds. Generally, between 70% and 80% of the posts flushed, except for the 10-day soaked control posts, which flushed 100% (Table 1).

Effects of Soaking Treatment on Willow Posts Within Each Soil Moisture Regime

Table 2 presents the results of the analysis of variance for each of the main effects (soaking, soil moisture) and the interaction between these factors for four key response variables (survival, total biomass, total length of live shoot growth, number of live roots). The results indicate that soaking posts before planting had a significant effect on all four variables. On the other hand, the effect of the soil moisture treatment was significant only for total biomass production ($p = 0.0063$). The interaction between these factors was significant for total biomass production ($p = 0.0036$) and the total length of live shoot growth ($p = 0.0376$) but not the number of roots produced per post ($p = 0.1647$) or for survival ($p = 0.2239$). Data analysis further indicated that the interactions between the soaking and soil moisture regime were significant for all biomass components; the relationship between these variables is presented in Figure 1. The 10-day soaked posts in the control soil moisture regime produced greater shoot ($p = 0.0020$), leaf ($p = 0.0024$), root ($p = 0.0030$), and total biomass ($p = 0.0012$) than did the 0- and 3-day soaked posts. Soaking effects were also noted in the permanently flooded soil moisture regime where shoot dry weight and total biomass production were greater in the 10-day soaked treatment in comparison with the 3-day treatment ($p = 0.0664$ and $p = 0.1019$, respectively, Fig. 1). Conversely, no significant effect of soaking was noted

Table 1. Growth data for black willow posts subjected to three soaking treatments (0, 3, and 10 days) and then grown under four soil moisture regimes (control, drought, permanently flooded, and intermittently flooded).

Variable	*Control*			*Drought*			*Flood*			*Intermittent Flood*		
	Soaking Treatment			*Soaking Treatment*			*Soaking Treatment*			*Soaking Treatment*		
	0-day	*3-day*	*10-day*	*0-day*	*3-day*	*10-day*	*0-day*	*3-day*	*10-day*	*0-day*	*3-day*	*10-day*
No. primary live shoots	1.29bB	5.57abAB	8.57aA	1.86aA	0.00	2.43aA	3.14abB	1.29bB	8.71aA	6.00aA	0.71aA	5.00aA
No. secondary live shoots	3.00aA	21.71aA	28.00aA	8.29aA	0.00	7.86aA	1.86aB	0.00aB	12.71aA	13.86aA	1.57aA	30.67aA
No. live shoots	4.29aA	27.29aA	36.57aA	10.14aA	0.00	10.29aA	5.00abB	1.29bB	21.43aA	19.86aA	2.29aA	35.67aA
Total length of live shoot growth	51.43bB	397.00aA	499.57aA	92.86aA	0.00	114.49aA	177.14abAB	50.14bB	444.86aA	376.43aA	53.86aA	213.00aA
No. live roots	4.00aA	75.14aA	104.57aA	23.14aA	0.00	6.00aA	24.43abB	3.57bB	81.86aA	21.86aAB	0.71aB	49.33aA
No. buds	8.00aA	6.29aA	7.29aA	9.86aA	9.57aA	3.71aA	6.71aA	5.43aA	6.14aA	8.29aA	2.86aA	5.57aA
% Posts with flushed buds	71aA	71aA	100aA	86aA	71aA	71aA	71aA	71aA	71aA	86aA	57aA	57aA
Root-to-shoot ratio	0.026bB	0.412aA	0.457aA	0.139aA	—	0.086aA	0.085aA	0.029aA	0.152aA	0.066aA	0.062aA	0.149aA
% Survival	29aB	71aA	86aA	29abB	0bB	71aA	43aA	29aA	71aA	43aA	29aA	33aA

Values are means per post and include the number of primary shoots (defined as a shoot originating from the post), number of secondary shoots (defined as a shoot originating from a primary shoot), total number of shoots, total length of live growth (cm), number of live roots, number of buds present 16 days after moisture regime initiation, the percentage of posts that flushed buds, root-to-shoot ratio, and the percentage of posts that survived through the experiment. (—, Root-to-shoot ratio could not be calculated due to death of posts in this treatment combination.) Lower-case letters next to each mean represent significant differences among soaking treatments within each soil moisture regime at the $p < 0.05$ level; upper-case letters represent significant differences at the $p < 0.10$ level. Variables followed by the same lower-case letter are not significantly different at the $p < 0.05$ level; variables followed by the same upper-case letter are not significantly different at the $p < 0.10$ level.

for biomass components in the intermittently flooded or drought soil moisture regimes (Fig. 1).

Soil E_H showed significant differences across soil moisture regimes ($p = 0.0001$). The control (+420 ± 34 mV [mean ± SE]) and drought (+451 ± 16 mV) regimes were in the range indicative of aerated soils (above +350 mV). In contrast, the intermittently flooded treatment showed considerable soil reduction during flooding periods (+158 ± 33 mV) and yet greater soil reduction in the permanently flooded treatment (+6 ± 41 mV). Soil E_H was significantly different across flooded treatments and different from the control and drought soil moisture regimes.

The root-to-shoot ratio was calculated for each post using total live aboveground and belowground biomass (Table 1). The effect of soaking was most obvious in the control treatment because the 10- and 3-day soaked posts had significantly greater root-to-shoot ratios than the non-soaked posts ($p = 0.0232$), indicating an increase in the amount of belowground biomass. For instance, although live shoot biomass increased 16-fold in 10-day soaked posts compared with control (42.57 ± 9.53 g vs. 2.51 ± 2.51 g), live root biomass increase was 32-fold (19.52 ± 4.27 g vs. 0.60 ± 0.59 g). The 10-day soaked posts showed an increase over non-soaked posts in the number of live roots of 2,600%, 335%, and 226% when grown in control, permanently flooded, and inter-

Table 2. MANOVA table for survival, total biomass production, total length of live shoot growth, and the mean number of live roots produced by black willow cuttings when subjected to three soaking treatments (0, 3, and 10 days) and then grown under four soil moisture regimes (control, drought, permanently flooded, and intermittently flooded).

	Sum of Squares	F *Value*	p *Value*
	Survival		
Soaking treatment (ST)	1.83	4.15	0.0198
Soil moisture regime (SM)	1.10	1.67	0.1816
ST × SM interaction	1.86	1.41	0.2239
	Total Biomass		
Soaking treatment	6796.7	5.91	0.0042
Soil moisture regime	7681.3	4.45	0.0063
ST× SM interaction	12403.8	3.60	0.0036
	Total Length of Live Shoot Growth		
Soaking treatment	547258.8	3.31	0.0423
Soil moisture regime	655841.2	2.64	0.0559
ST × SM interaction	1180805.0	2.38	0.0376
	Number of Live Roots		
Soaking treatment	31060.5	3.80	0.0271
Soil moisture regime	30029.8	2.45	0.0708
ST × SM interaction	38853.8	1.58	0.1647

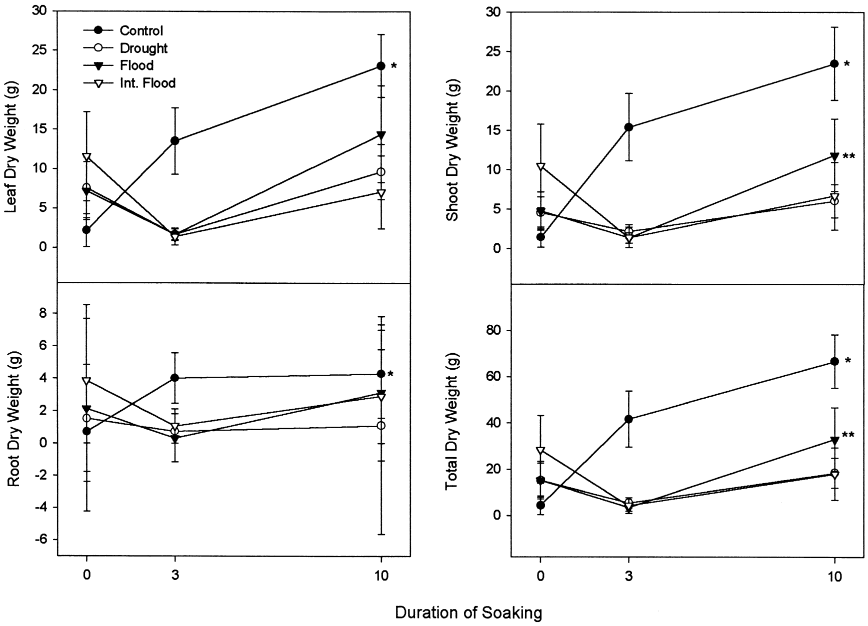

Figure 1. Interaction diagrams indicating response trends for leaf, shoot, root, and total biomass for posts subjected to 0, 3, or 10 days of soaking before planting in control (●), drought (O), permanently flooded (▼), and intermittently flooded (∇) soil moisture conditions. *Significant difference between the 10-day and either the 3- or 0-day soaking treatments at the $p < 0.10$ level. **Significant difference between the 10-day and 3-day soaking treatment at the $p < 0.05$ level.

mittently flooded soil moisture regimes, respectively (Table 1). Additionally, in the control soil moisture regime the number of primary live shoots was greater for 10-day soaked posts than the 0-day soaked treatment ($p = 0.0352$). The total length of live shoot growth in the control regime was also greater in both soaked treatments than in the non-soaked ($p = 0.0206$), with increases as large as nearly 10-fold (499.57 ± 129.83 cm vs. 51.43 ± 51.43 cm). Under flooded conditions, the 10-day soaked posts showed a significant increase in the number of primary live shoots and the total length of live shoot growth over the 3-day soaking treatment ($p = 0.0714$ and $p = 0.1061$, respectively). In intermittently flooded conditions, soaking did not produce any significantly detectable effects (Table 1). However, the number of live roots was 125% higher in 10-day soaked posts compared with controls (non-soaked). The number of secondary live shoots in the 10-day soaking treatment was more than double that of non-soaked posts (30.67 ± 21.08 vs. 13.86 ± 5.32).

The survival rate varied across treatment combinations (Table 1). Significant differences in survival were noted in both the control and drought soil moisture regimes. In the control, 10-day soaked posts had the highest survival rate (86 ± 14%) followed by the 3-day (71 ± 18%), whereas the survival was lowest (29 ± 18%) for the 0-day soaked posts ($p = 0.0751$). Similarly, in the drought treatment the 10-day soaked posts had the highest survival rate at (71 ± 18%), notably outperforming the non-soaked and 3-day soaked treatments ($p = 0.0121$). Survival data for the flooded regime followed a similar pattern (Table 1). Again, 10-day soaked posts survived best (71 ± 18%). The soaking treatment did not appear to have any substantial impact on survival rates under intermittently flooded conditions.

Effects of Soaking Treatment on Willow Posts Across All Soil Moisture Regimes

The beneficial effects of soaking on willow post performance across soil moisture regimes are apparent in the biomass data. The dry weights produced for various biomass components were consistently and significantly greater in the 10-day soaking treatment than the 3-day and 0-day soaking treatments (Fig. 2). The root ($p = 0.0406$), shoot ($p = 0.0120$), leaf ($p = 0.0059$), and total biomass ($p = 0.0111$) produced for the 10-day treatment was at least two times greater than other treatments. Soaking for 3 days did not improve biomass production over the non-soaking treatment. Posts soaked for the longest duration had a root-to-shoot ratio at least twice that of other treatments ($p = 0.0887$, Table 3).

Growth of posts was also significantly enhanced by 10 days of soaking. Posts soaked for 10 days produced three times as many roots as posts soaked for 0 or 3 days ($p = 0.0337$). This represents a substantial increase in root surface area for water and nutrient absorption. Similarly, the number of primary live shoots ($p = 0.0138$), the number of secondary shoots ($p = 0.0346$), and the total length of live shoot growth ($p = 0.0569$) showed significant increases with increased soaking duration (Table 3). In addition, the 10-day soaked posts had a significantly greater survival rate (67 ± 9%) than the 3-day or 0-day (32 ± 9% and 36 ± 9%, respectively; $p = 0.0176$). Thus, increasing the length of pre-planting soaking improved not only the amount of growth and bio-

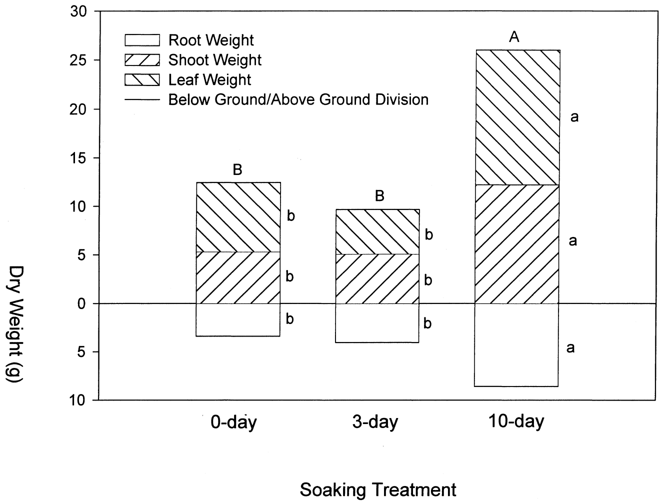

Figure 2. The effect of three pre-planting soaking treatments (0, 3, and 10 days) across soil moisture regimes on root, shoot, and leaf biomass production of black willow cuttings. Different letters next to each biomass partition represent significant differences for that biomass component across treatments. Uppercase letters above each bar represent significant differences for the total biomass produced. The significance level used was $p < 0.05$.

mass of black willow posts, but also the potential for long-term survival.

Discussion

Pre-planting soaking clearly enhanced survival and growth in black willow posts in the present study. Across soil moisture regimes, soaking for 10 days increased virtually all measured biomass (Fig. 2), growth, and survival (Table 3) parameters. Soaking had no significant effect on the number of buds produced by posts or the percentage of the posts that flushed (Table 3). Therefore, the increase in shoot biomass and growth were a result of increased root development and the subsequent enhancement of water and nutrient uptake. The number of secondary shoots was significantly greater for the 10-day soaking treatment (Table 3). Thus, soaking posts not only had a positive effect on the number of shoots produced, but also on crown architecture. Combined with enhanced leaf production, soaking resulted in increased net area for photosynthetic activity.

Beneficial effects of soaking on growth (Table 1) or productivity (Fig. 1) of willow posts grown under the various soil moisture regimes were limited to the control treatment. When soil moisture was maintained at field capacity, biomass production increased significantly under the 10-day soaking regime (Fig. 1). However, trends in growth patterns were not as consistent. Previous reports (Hansen & Phipps 1983) of the effects of soaking on other woody species indicated that 10 days after planting, nearly 100% of cottonwood posts warmed and soaked for 10 days had already flushed, whereas no flushing occurred for posts that had not been soaked. Similarly, soaked posts consistently flushed earlier and produced longer shoots when grown in soil moisture tensions ranging from 0.25 MPa in comparison with non-soaked posts (Hansen & Phipps 1983). The current study found no soaking effect on the percentage of willow posts that flushed buds or the average number of buds produced. However, *Salix* spp. are generally considered easier to root and grow vegetatively than *Populus* spp. (USDA Natural Resources Conservations Service 1996), which may reflect willow's ability to initiate early growth structures.

Previous studies also reported increases in the number and dry weight of roots for *Populus* species when cuttings were subjected to a soaking pretreatment (Pe-

Table 3. Growth variables measured for black willow cuttings subjected to various durations of pre-planting soaking across soil moisture regimes.

	Soaking Treatment		
Variable	*0-day*	*3-day*	*10-day*
No. primary live shoots	3.07bB	1.89bB	6.22aA
No. secondary live shoots	6.75bB	5.82bB	19.41aA
Total no. live shoots	9.82bB	7.71bB	25.63aA
Total length of live shoot growth	174.46abB	125.25bB	321.87aA
No. live roots	18.36bB	19.86bB	60.89aA
No. buds	8.2aA	6.0aA	5.7aA
% post with flushed buds	79aA	68aA	75aA
Root-to-shoot ratio	0.10aB	0.10aB	0.22aA
% Survival	36bB	32bB	67aA

Lower-case letters next to each mean represent significant differences among soaking treatments within each soil moisture regime at the $p < 0.05$ level; upper-case letters represent significant differences at the $p < 0.10$ level. Variables followed by the same lower-case letter are not significantly different at the $p < 0.05$ level; variables followed by the same upper-case letter are not significantly different at the $p < 0.10$ level. Growth measurements include the mean number of live, primary, and secondary shoots; mean total length of primary shoots (cm); mean number of live roots; mean number of buds per post; percentage of posts that flushed buds; root-to-shoot ratio for each post; and percent survival.

tersen & Phipps 1976; Phipps et al. 1983) and when planted in potting medium with high soil moisture (Deka et al. 1988; Rein et al. 1991). The patterns of rooting in black willow in this study showed similar trends within certain soil moisture regimes. Posts grown at soil moisture around field capacity increased root numbers and biomass in response to longer soaking duration. However, in the drought and permanently flooded soil moisture regime, these trends were not observed. In each case, the overwhelming effects of adverse soil moisture conditions counteracted the benefits of the soaking pretreatment (Fig. 1). Previous experiments tested the effects of soaking within the first few weeks of growth (Petersen & Phipps 1976; Hansen & Phipps 1983; Rein et al. 1991); thus, soil conditions probably had less impact on the growth of root and shoot structures. It is interesting to note that soaking posts for 10 days resulted in much greater survival under drought conditions (Table 1). This was unexpected due to the known sensitivity of black willow to drought and the overwhelming impact such stress has on the physiological functioning of this species (Pezeshki et al. 1998).

This study clearly demonstrates that across a range of soil moisture conditions, soaking posts for 10 days improved growth, biomass production, and survival. In the field, unlike in this experiment, enhanced root initiation and elongation provide the opportunity for the post to exploit and expand into soil horizons. Restoration projects typically plant willow cuttings in the spring when soil moisture is favorable. Thus, soaking-induced increases in root growth coupled with favorable soil moisture conditions may allow posts to extend the root zone into aerated but moist soils. Such root expansion creates additional opportunity for water and nutrient uptake and growth, leading to flood and drought avoidance later in the growing season.

The soaking treatment appears to improve root growth and subsequent biomass production of cuttings in several ways. First, placing hardwood cuttings in water promotes rapid root development (de Philippis 1966; McNight & Biesterfeldt 1968; Hansen & Phipps 1983; Phipps et al. 1983); consequently, root primordia develop to a stage where functional roots emerge shortly after planting. Early emergence and rapid root elongation have been shown to result in significant increases in growth and survival in poplar cuttings (Tschaplinski & Blake 1989; Flygh et al. 1993). Rein et al. (1991) noted that the presence of as few as one or two roots substantially increased mid-day xylem pressure potential compared with unrooted cuttings. Therefore, the promotion of a favorable water balance for unrooted cuttings is critical for subsequent growth. Soaking increases the total water content of the post, allowing water stress avoidance before and during early stages of growth (Pallardy & Kozlowski 1979; Grange & Loach 1983; Hansen & Phipps 1983; Ikeda & Suzaki 1986; Deka et al. 1988). Poplar cuttings warmed and soaked for 10 days before being planted in a range of soil moisture tensions produced roots regardless of soil moisture regime (Hansen & Phipps 1983). In contrast, warming and soaking posts for 4 days enhanced rooting when grown in moist soils but not in dry soils. The authors concluded that improved water content of the post provided by extended periods of soaking supplied sufficient moisture for the early growth needs of the cutting, whereas posts soaked for shorter periods may be subject to desiccation as soil and/or tissue moisture availability decreases.

The scope of this study was of applied interest, so willow posts were selected in a manner identical to stock selection at a project site. Thus, data analysis incorporated all posts regardless of stock quality; for example, posts with no root or shoot production were included as well as posts that produced abundant biomass. Stock quality was an obvious factor for post survival. For instance, in this study approximately 70% of the posts produced buds within the first 16 days after planting. Of the 30% that did not produce buds, 77% failed to produce biomass (data not shown). In other words, approximately 20% to 25% of all posts failed due to poor stock quality. In typical field projects, posts are harvested during the period of December through March while the posts are dormant. Thus, it is difficult to determine if posts are taken from poor parent material. Also, as black willow experiences drought conditions, trees die from the top down (greenhouse observation). This pattern compounds the problem of parent tree health because posts harvested for restoration projects may be alive at the base and dead at the top. Upon planting, the live portion of the post is buried deep in soil, eliminating the possibility of survival. Therefore, it appears that a considerable percentage of post death may be attributed to poor stock quality.

There appears to be a temporal relationship between soaking duration and root biomass production and mean number of roots produced, such that increased duration of pre-planting soaking resulted in increases in both. In each case, posts soaked for the longest time produced more roots and more root biomass than did posts that were not soaked: Posts soaked for 3 days showed slightly greater or similar values than the non-soaked posts (Table 3, Fig. 2). Similar results have been reported for several *Populus* clones (Hansen & Phipps 1983; Phipps et al. 1983). The lack of response noted in the 3-day soaked posts (Table 3) may be due to a biological threshold that must be met before increased water content in the post results in increases in root and subsequent shoot biomass. If this was the case, then the relationship between soaking duration and growth response would be expected to increase exponentially rather than linearly. Additional research must be conducted using a wide range of soaking duration encompassing longer soaking periods to identify optimum soaking duration and growth response patterns for black willow.

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